NAIC-ID(RS)T-0440-96

NATIONAL AIR INTELLIGENCE CENTER

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NAIC-ID(RS)T-0440-96

HUMAN TRANSLATION

NAIC-ID(RS)T-0440-96 15 October 1996

MICROFICHE NR:

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English pages: 12

Source: Laser Technology; pp. 141-145

Country of origin: China
Translated by: Leo Kanner Associates
F33657-88-D-2188
Requester: NAIC/TATD/Bruce Armstrong
Approved for public release: distribution unlimited.

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RESEARCH ON CONTROL AND PROTECTION STANDARDS FOR LASER HAZARDS

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ABSTRACT

The research methods and results of control and protection standards for laser hazards are introduced in this paper. The scientific basis for the established standards are described. The content and characteristics of the standards are briefly explained.

The controls and protection standards for lasers, the drafting of which was the responsibility of the Chinese Peoples Liberation Army Medical Science Academy, Radiology Institute, Laser Medicine Laboratory, has already been published by the Commission for Science and Industry in National Defense and is being carried out by more than 200 units in 21 provinces, cities and autonomous regions throughout China. This is the first set of universal technical regulations for laser safety and protection in China. In order to help those units carrying out these regulations to understand these standards and to promote the thorough implementation of these standards, this paper will provide a brief explanation of how these standards were drawn up, what they are based on, their content and their characteristics.

I. Introduction

As everyone knows, lasers are already being widely used in many fields, especially in military fields where equipment such as laser range finding, tracking, guidance, targeting instructions,

communications and simulated firing are being used in large numbers in foreign militaries. Lasers blinding and strong laser weapons are drawing attention because of their special destructiveness. They are one more advance in modern weapons development. They will be widely used in the military in the future. However, a great deal of research into their biological effects have demonstrated that lasers represent a certain threat to human health, particular to the eyes and skin. Excessive exposure to laser rays can cause keratitis, cataracts, burning of the retina as well as blindness. Exposure to certain amount of laser radiation can cause varying degrees of skin damage such as accelerated aging of the skin, produce chromatosis, erythema and tissue carbonization, and prolonged exposure to ultraviolet laser rays can cause skin cancer. There are also reports of effects of prolonged exposure to low power laser radiation to the cardiovascular systems, nervous systems and reproductive systems of occupational workers. Therefore, shortly after the appearance of lasers, foreign scholars began to study the danger of lasers and safety and protection. After 1970, a number of countries and international organizations began establishing national standards, international standards and military standards for various types of lasers, a number of which have been revised a number of times[1].

Laser development in China has been very rapid, and military applications are fairly widespread. However, research on laser safety and protection began relatively late. The dangers of lasers have still not attracted widespread attention, and laser accidents and injuries occurred frequently[2]. Beginning in 1985, a three year study was conducted using biological effect testing and surveys of eye injury accidents to study the problem of laser control and protection and to draft the relevant technical regulations. The purpose of this study was to prevent personnel involved in the research, production, use and maintenance of lasers

from injuries or harmful effects of lasers and to promote the development of laser technology.

II. The Technology Route

1. Studying the Safe Use of Lasers

In order to make these standards conform to the actual situation in China and the Chinese military, the comrades on the standards drafting group first read a large number of articles on lasers and then visited 43 scientific research and production units and military units where they conducted on-site surveys, discussions and interviews with experts to reach an overall understanding of the types of lasers which our military currently possesses, their wave bands, where they are used and the developmental trends and conducted a key point survey of control and protection measures against laser injury and problems which exist in safe use of lasers: Their findings were:

Laser range finding, simulated firing, tracking guidance and target indication are already being applied to varying degrees. Some are being supplied to units in large numbers. Laser simulated firing is has already developed from single branch of the military for training to joint training exercises with all three branches of the service. This includes use by some schools for the infantry, artillery, armored forces, air forces and naval forces. There are already a number of different laser models with wave lengths which range from visible light to infrared, with the giant pulse Nd:YAG and its frequency multiplier lasers which represent a greater threat to health most widely used.

There is universal concern among the broad masses of personnel who develop, produce and use lasers about the danger of lasers. A

few units have adopted certain protective measures, but overall, this problem has not yet attracted sufficient attention from leadership departments. Most units have not yet established a strict system of regulations. A fairly large percentage of the personnel do not have sufficient understanding of laser safety and protection. The laser products currently in use have not been categorized by the threats they constitute, so no corresponding danger control measures exist. Some units only emphasize the tactical instructions for lasers and are not concerned with their safety properties. There is no uniform laser measuring method or measuring standard throughout the military. This problem is a potential threat to the health of the personnel.

This situation provided the basis for determining the standards and range of applications.

2. The Biological Effects of Lasers and Patterns of Injuries

The degree to which lasers are a threat to health is closely related to the wave length, time of exposure, radiation intensity and other physical factors as well as such biological factors as the portion of the body exposed to laser light and the light spectrum properties of the tissue. In order to understand the patterns of injury, on the basis of the work by the "All-China Laser Safety and Protection Research Coordination Group"[3], tests were conducted on the biological effects of some of the military lasers on the eyes and skin[4]. Tables 1 and 2 show the injury thresholds of different wavelengths of laser light on the eyes of 1635 rabbits and on the skin of 109 volunteers.

Tab. 1 Rabbit eye injury thresholds to typical laser light exposure

1 激光器	2 辐射波长 (nm)	3 照射时间 (s)	4 损伤阈值 (J/m^2)
KCl	222	8.0×10^{-9}	5.4×10^{2}
XeCl	308	8.0×10^{-9}	8.3×10^{3}
Ar^+	488～514.5	1.0	4.0×10^{3}
倍频YAG	532	5.0×10^{-9}	3.9×10^{-1}
He-Ne	632.8	1.0	1.8×10^{3}
Ruby	694.3	6.0×10^{-4}	1.5×10^{2}
YAG	1064	1.0	2.5×10^{4}
		5.0×10^{-9}	1.2×10^{1}
CO_2	10600	1.0	3.6×10^{4}
		1.8×10^{-7}	2.6×10^{3}

1. Laser. 2. Wavelength (nm). 3. Exposure time (s). 4. Injury threshold (Jm^2).

Tab. 2 Human skin injury threshold to typical laser light exposure

1 激光器	2 辐射波长 (nm)	3 照射时间 (s)	4 损伤阈值 (J/m^2)
Ar^+	488～514.5	1.0	5.6×10^{4}
Ruby	694.3	3.2×10^{4}	4.7×10^{4}
YAG	1064	1.0	6.1×10^{5}
		2.0×10^{-4}	9.9×10^{4}
CO_2	10600	1.0	2.7×10^{4}
		1.8×10^{-7}	4.3×10^{3}

1. Laser. 2. Wavelength (nm). 3. Exposure time (s). 4. Injury threshold (J/m^2)

After analyzing these data we have come to the following conclusions:

(1). Different wavelength laser light at the same exposure times resulted in different injury thresholds on the same eye location, with green laser light being the lowest. With an exposure time of $5X10^{-9}$ seconds, the rabbit eye retina damage threshold for 532 nm laser light was three degrees of magnitude lower than for 1064 nm laser light.

(2). Exposure to the same wave length of laser light for different exposure times also resulted in different injury thresholds, with the giant pulse layer injury threshold being lower. Using a 1064nm wavelength laser, the injury threshold of an exposure time of $5X10^{-9}$ seconds was three orders of magnitude less than that of one second.

(3). Different wavelengths and different exposure times can result in different degrees of injuries to human skin, with visible light and near infrared lasers having an injury threshold to human skin one order of magnitude greater than that of far infrared lasers, and long pulse (or continuous pulse lasers) having an injury threshold of about a one order of magnitude greater than a giant pulse laser.

In order to further understand the differences in laser radiation for the same degree of injury for rabbits and human eyes, we combined the experiments with clinical data, selecting appropriately eyes with macula retinae to conduct real time measuring of the radiation treatment while carrying out light congealing therapy as well as the radiation time and the size of the light spot on the back of the eye, obtaining their relationship with the amount of injury to the human eye. We compared this with

the same amount of injury to the rabbits' eyes, providing a connection between the amounts of exposure. The results were that human eyes require 3.5 to 6.6 as much laser exposure than rabbits (see Table 3)[5].

Tab. 3 Comparison of injury to rabbit and human eyes

1 激光器	2 辐射波长 (nm)	3 照射时间 (s)	4 损伤阈值比	
			5 兔	6 人
Ar^+	488～514.5	1.0×10^{-1}	1	3.5
		2.4×10^{-2}	1	6.6
YAG	1064	1.5×10^{-4}	1	4.3

1. Laser. 2. Wave length (nm). 3. Radiation time. 4. Injury threshold level. 5. Rabbits. 6. Humans.

These results provide a biological basis for determining the human eye and skin exposure limits (also called maximum permissible exposure) for different wavelengths and different exposure times.

3. Survey of human eye injury accidents involving lasers

The eye thresholds and patterns of injuries for different types of lasers have been obtained through a large number of animal experiments. In order to further explore the relationship of the amount of laser radiation and the effects on vision of laser eye injuries and the degree of damage in order to draft control measures against laser threat, we surveyed and analyzed 29 cases of eye injuries caused by lasers in seven provinces and two cities to obtain data not attainable through animal experiments. The results

of this survey and analysis are:

(1). All of the injury causing lasers were military lasers. Of these, 21 were directly caused by the Nd:YAG giant pulse laser which is widely used in the military.

(2). There were more injuries due to reflected light than direct radiation. The reflected medium was mostly various types of optical glass, crystals, knives, photographic paper and plastic film.

(3). There were more injuries within than outside of the macula retinae, and 81 percent of the injuries were within the macula retinae. This indicates that the patients were within the light beam looking towards the laser source.

(4). The vast majority (26) of the patients were people who worked with lasers.

(5). All of the accidents were caused by carelessness, insufficient safety measures and ineffective control measures. None of the patients were wearing safety goggles.

These results are of major reference value in drafting control and protection measures for laser hazards.

4. Soliciting opinions and recommendations from many areas

The solicitation of opinions and recommendations is an important measure for ensuring that standards are advanced, scientific and practical. Therefore, for our standards, we solicited opinions and recommendations from more than 100 military units developing, producing and using lasers. We collected

recommendations from specialists in the field, thus insuring that the standards sere scientific and strict.

Based on the results of these four studies, referring to reference materials[6-9], and in accordance with the standards drafting procedure, we drafted the technical contents of these standards.

III. Primary contents and characteristics of the standards

These standards stipulate methods of rating the hazards of military lasers, requirements for control measures and personnel protection, and are applicable to laser research and development, production, repair, maintenance, property testing and military training. The entire standards consists of four chapters and three appendices, about 40,000 characters. The primary contents are:

1. They stipulate the basic requirements and steps in rating the hazards of military lasers from the aspects of laser output parameters, type of hazards, warning markings and environment in which used. They also provide methods of calculating the hazardous distance for categories 3B and 4 lasers.

2. They stipulate the eye and skin radiation limits for parallel, scattered and repeat frequency lasers from the ultraviolet to the infrared spectrum. Table 4 lists typical data showing two to three orders of magnitude lower than the injury threshold for rabbit eyes and one to three orders of magnitude for human skin.

Tab. 4 typical laser radiation eye and skin radiation standards

1 激光器	2 辐射波长 (nm)	3 照射时间 (s)	4 眼照射限值 (J/m^2)	5 皮肤照射限值 (J/m^2)
KCl	222	10^{-8}	30	30
XeCl	308	10^{-8}	4×10^{2}	4×10^{2}
Ar^+	488~514.5	1.0	18	1.1×10^{4}
倍频YAG	530	10^{-8}	5×10^{-3}	2×10^{2}
He-Ne	632.8	1.0	18	1.1×10^{4}
Ruby	694.3	10^{-3}	7.7×10^{-2}	1.8×10^{3}
GaAs	900	1.0	45	1.1×10^{4}
YAG	1064	10^{-8}	5×10^{2}	2×10^{2}
CO_2	10600	1.0	5.6×10^{2}	5.6×10^{2}

1. Laser. 2. Wavelength (nm). 3. Radiation time (s). 4. Eye radiation threshold (J/m^2). 5. Skin radiation threshold (J/m^2).

3. Hazard control measures for different models of lasers. Under common conditions, indoor lasers are primarily controlled through engineering, and those used outdoors are primarily controlled through handling. These standards also stress methods of controlling the hazards of reflected light.

4. Requirements for personal eye and skin protection. The key points of these requirements are eye protection. The most effective of method for this is to wear protective goggles. Therefore, the standards also stipulate the primary capability parameters of protective goggles.

5. These standards stipulate principles for rating the hazards of lasers and for measuring the protection parameters (amount of radiation, light density), the measurement hole diameter, how to check the testing device and measurement error.

The standards also include the appendices "laser safety management, "computational examples of different types of lasers" and examples of rating the hazards of lasers" for further illustration.

Compared to other standards in China and in foreign countries, these standards are characterized by: They are based on large amount of studies and on data from biological effects experiments, especially on data from the eyes and skin of Chinese people. The standards are safe and reliable and give prominence to the characteristics of military lasers. They provide methods of rating the hazards and control measures for the different branches of the service and different operational environments. The opinions of experts in the fields and unit commanders and men were solicited, and the standards conform to reality. They are very focussed and easy to carry out. In a review by 27 military units, the conclusion reached was that "these standards conform to the situation which exists in China and to the direction in which science and technology is headed. The technology is advanced, safe and reliable. It is economically reasonable. The technical indexes of these standards are in the forefront in China and around the world. They achieve the levels of foreign countries of the middle eighties.

In the process of drafting these standards, we received a great deal of support from laser workers in the military and outside of the military, especially from units developing, producing and using military lasers, and we take this opportunity to express our gratitude for this support.

Date received: June 11, 1991

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